

PRELIMINARY STUDY OF SALINITY AND TEMPERATURE EFFECTS ON SOIL MOISTURE CAPACITANCE PROBES

S.A. Barber¹ and S.R. Raine²

¹ Queensland Fruit & Vegetable Growers Ltd, Toowoomba, 4350.

² National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba, 4350.

ABSTRACT

The Queensland Fruit and Vegetable Growers Ltd *Water for Profit* program has been actively involved in the promotion of improved irrigation management, including the use of appropriate scheduling devices. As part of the program, a wide range of soil water sensors have been installed and utilised under a variety of commercial conditions. Inconsistencies in capacitance sensor responses obtained under some field conditions, and concerns regarding sensor accuracy raised by rival equipment suppliers, led to a preliminary study being undertaken. This study was to investigate the effect of salinity and temperature on the responses obtained from two brands of capacitance sensor.

The effect of salinity and temperature were investigated in separate laboratory trials. The capacitance sensors used in each trial were the Sentek EnviroSCANTM and Dataflow BuddyTM. The results indicate that as the soil salinity increased, the apparent saturation and field capacity of the soils as measured by the sensors increased. Similarly, as soil temperature increased, the apparent moisture contents measured by the sensors increased. The magnitude and significance of these differences, the variation in response between the sensors and the implications for field monitoring are discussed.

Key words: Soil Moisture Monitoring, Capacitance Probes, EnviroSCANTM, BuddyTM, Salinity, Temperature.

INTRODUCTION

Capacitance sensors apply an electric field to measure the dielectric constant of a given medium, be it the soil matrix (<10), water (80) or air (1). The capacitor is electronic circuitry within a cylinder, with two outside metal bands (ie. electrodes) separated by a distance of 5-8cm. The electrical field produced by the electrodes extends approximately 50% further from the bands than the distance separating the two electrodes (Kutilek and Nielsen, 1994). Soils are a changeable medium consisting of solid, water and air components which varies the dielectric constant. Measurement of the dielectric constant of a soil can be used to estimate the moisture content. However, the relationship between the change in the dielectric constant and soil water content depends on the soil type and the frequency range of the apparatus.

Soil moisture equipment manufacturers and suppliers commonly claim that their capacitance sensors should not be affected by either soil temperature or salinity. Previous research (Dean *et al.*, 1987) suggests that sensors operating at a frequency greater than 100 MHz should overcome interfacial polarization effects and have a minimal sensitivity to salinity. However, evaluation and calibration of capacitance sensor performance by some workers (eg Mead *et al.*, 1995; Baumhardt *et al.*, 2000) suggests that soil density, water salinity and temperature all have some effect on the accuracy of sensor measurements. Growers involved with the Queensland Fruit & Vegetable Growers Ltd *Water for Profit* program have also raised concerns regarding the effect of both temperature and salinity on the accuracy of field measured soil moisture capacitance readings. Hence, a preliminary laboratory trial was conducted to quantify the sensitivity of two commercially available capacitance sensors to salinity and temperature fluctuations.

MATERIALS AND METHODS

All trials were conducted in a laboratory using a red medium clay which had previously been air-dried and passed through a 4.75mm mesh sieve. The soil was loosely packed into containers and wetted to approximately 10% volumetric moisture content before being subjected to a range of either salinity or temperature treatments. EnviroSCAN (Sentek Pty Ltd, Adelaide, SA) and Buddy (Dataflow Pty Ltd, Cooroy, Qld) sensors were used to measure the capacitance in each treatment with results reported as either a raw count or apparent soil moisture content based on the default calibration for each sensor.

Salinity

Two large soil bins (0.25m deep x 0.5m wide x 0.9m) with drainage holes in the bases were filled with soil. PVC access tubes for the EnviroSCAN and Buddy sensors were located along the centreline of each container to minimise any interaction between the sensors or container edge effects (Figure 1). Treatments consisted of flushing the soil bins with different concentrations of sodium chloride solution to simulate a range of irrigation water qualities (120, 1500, 2200, 3000 and 9000 $\mu\text{S}/\text{cm}$). The first treatment applied was rainwater (120 $\mu\text{S}/\text{cm}$) with subsequent treatments sequentially increasing the salt concentration of the applied water. The solutions were applied to the pots until the leachate was within 15% of the electrical conductivity of the input water quality. After each treatment, the soil was allowed to drain for 24 hours prior to applying the next salinity treatment. Gravimetric moisture sampling was undertaken at saturation and field capacity throughout the treatments to quantify any change in soil moisture content due to soil structural changes.

Temperature

To evaluate the effect of temperature on the capacitance sensors, Enviroscan and Buddy sensors were housed in their specified PVC access tubes, centered in separate containers (0.35m deep \times 0.35m wide \times 0.29m) and surrounded with either air, water or the prepared soil before being sealed with plastic and tape. Treatments consisted of placing the Buddy/EnviroSCAN containers in a cold room (4°C), oven (38°C) and constant temperature laboratory (22°C). The sensors outputs were recorded at 1 minute intervals and the times that the cold room fan started and stopped were manually recorded to identify electrical interference that may have affected the capacitance readings.



Figure 1: Capacitance sensors installed in a soil bin with water quality treatment being applied.

RESULTS

Increasing the salinity of the irrigation water was found to decrease the raw count and increase the apparent soil moisture content recorded by both the Buddy (Figure 2) and the EnviroSCAN (Figure 3) capacitance sensors. For the Buddy sensor, increasing the water salinity from 1500 to 3000 $\mu\text{S}/\text{cm}$ resulted in an average decrease in raw count of 28 counts at soil saturation and 46 counts at field capacity (Figure 2a) and resulted in an apparent increase in soil moisture of 0.55% at saturation and 0.2% at field capacity (Figure 2b). Over the full range of water qualities used (120-9000 $\mu\text{S}/\text{cm}$) the decrease in raw count was 107 at saturation and 91 at field capacity while the apparent soil moisture increased by 1.6% at saturation and 1.9% at field capacity.

For the EnviroSCAN sensor, increasing the water salinity from 1500 to 3000 $\mu\text{S}/\text{cm}$ decreased the raw count measured by 460 for the saturated soil and by 361 for the soil at field capacity. This resulted in an increase of 4% at saturation and 8% at field capacity in the apparent soil moisture measured. Over the full range of water qualities used (120-9000 $\mu\text{S}/\text{cm}$), the raw count decreased by approximately 1086 counts at saturation and 1041 counts at field capacity resulting in an increase in the apparent soil moisture content of 11.5% at saturation and 11% at field capacity.

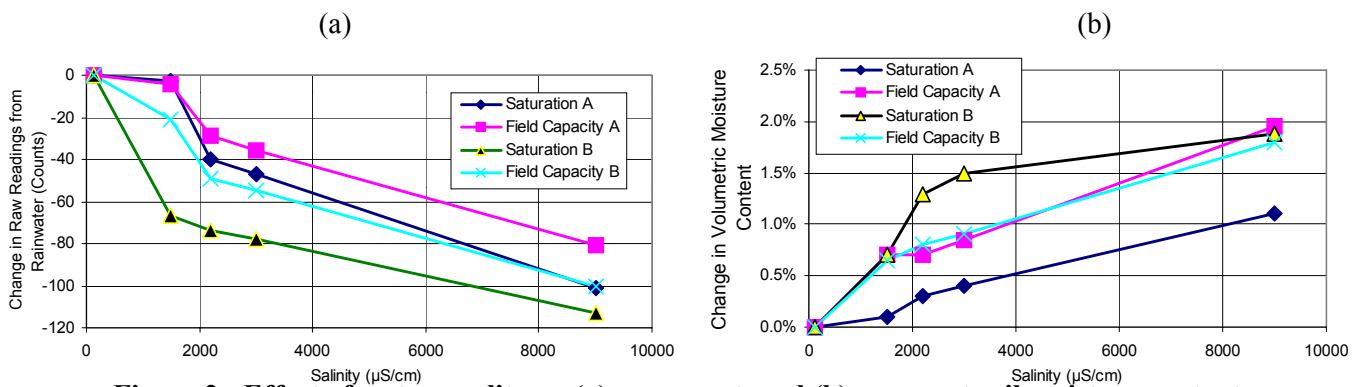


Figure 2: Effect of water quality on (a) raw count and (b) apparent soil moisture content for a Dataflow Buddy capacitance sensor (Default calibration: Clay – Slope = 40°)

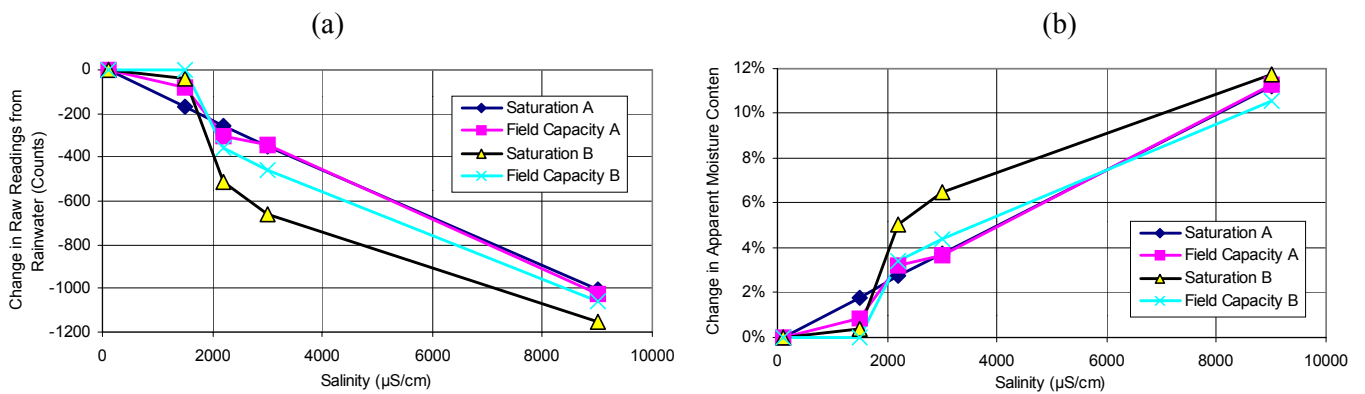


Figure 3: Effect of water quality on (a) raw count and (b) apparent soil moisture content for a Sentek EnviroSCAN capacitance sensor

(Default calibration: Air count = 37296 at 22 °C, Water count = 24904 at 22 °C, A = 0.1957, B = 0.404, C = 0.02852)

Increasing the temperature resulted in a raw counts decrease and an increase in the apparent moisture content for both the Buddy and EnviroSCAN sensors (Tables 1-4). The effect of temperature change was greatest in the water treatments and smallest in the air treatment for both sensors. For the Buddy sensor, increasing the temperature from 4 to 22 °C resulted in a relatively small difference in raw count of ~0.5% in water and ~0.6 % in air (Table 1). However, increasing the temperature from 22 to 38 °C resulted in a 21% change in raw count for the water treatment and a 1.7% change in air. This translates to a difference in apparent moisture content across the whole temperature range of between 1.9 and 5.2% depending on the medium measured (Table 2). The effect of temperature on the raw count and apparent moisture content measured using the EnviroSCAN was almost linear across the temperature range measured. Between 4 and 38 °C, raw count decreased by 0.3% in the air and 1.7% in the water treatments (Table 3). This resulted in an increase in apparent moisture content of between 0 and 3.7% depending on the medium.

Table 1: Effect of temperature on raw counts measured using a Buddy capacitance sensor

°C	Air		Water		Soil	
	Raw Counts	Difference	Raw Counts	Difference	Raw Counts	Difference
4	2294	14	660	3	1234	29
22	2280	0	657	0	1205	0
38	2242	-38	520	-137	1093	-113

Table 2: Effect of temperature on apparent moisture content measured using a Buddy capacitance sensor

°C	Air		Water		Soil	
	Moisture %	Difference	Moisture %	Difference	Moisture %	Difference
4	-9.35	-1%	30.2	-3.8%	16.1	-2.1%
22	-10.35	0%	34	0%	18.2	0%
38	-11.2	0.85%	35.4	1.4%	19.2	1%

Default calibration: Clay – Slope = 40°

Table 3: Effect of temperature on raw count measured using an EnviroSCAN capacitance sensor

°C	Air		Water		Soil	
	Raw count	Difference	Raw count	Difference	Raw count	Difference
4	37345	49	25075	171	29100	185
22	37296	0	24904	0	28915	0
38	37240	-56	24648	-256	28738	-177

Table 4: Effect of temperature on apparent moisture content measured using an EnviroSCAN capacitance sensor

°C	Air		Water		Soil	
	Moisture %	Difference	Moisture %	Difference	Moisture %	Difference
4	0.0028	0%	43.04	-1.47%	16.49	-0.9%
22	0.0044	0%	44.51	0%	17.39	0%
38	0.0066	0%	46.76	2.25%	18.28	0.89%

Default calibration: Air count = 37296, Water count = 24904, A = 0.1957, B = 0.404, C = 0.02852

DISCUSSION

The moisture contents measured using both the EnviroSCAN and Buddy capacitance sensor were found to be affected by both water quality and temperature fluctuations. This finding is consistent with the observations reported by other workers (eg. Mead *et al.*, 1995; Baumhardt *et al.*, 2000) and the expected effect of salinity and temperature on the permittivity of the soil constituents. However, the magnitude of the variations observed would be expected to make little difference to the usefulness of either instrument under normal field operating conditions for horticultural farms in Queensland. On these farms, variations in water salinity between irrigations and temperature fluctuations during the season are normally small (particularly at depth in the soil profile where soil moisture is being measured) compared to the range of salinities and temperatures applied in these trials. It should also be noted that many growers use capacitance sensors as a relative measure of soil moisture content to track water movement and extraction. In these cases, the effect of the changes identified in soil moisture content due to salinity or temperature fluctuations would be expected to be negligible.

While the general response of the sensors to salinity and temperature changes were consistent, the size and nature of the responses were different between the sensors. For example, EnviroSCAN and Buddy sensors operating under field conditions where the irrigation water quality applied has an electrical conductivity of less than 1500 $\mu\text{S}/\text{cm}$ would be expected to produce errors of less than 1% in the absolute moisture content measured due to variations in the water quality. However, where the electrical conductivity of the water applied varies up to 3000 $\mu\text{S}/\text{cm}$, this error in the apparent soil moisture could be expected to increase by up to 1.5% for the Buddy sensor and up to 6.5% for the EnviroSCAN. It should be noted that for both capacitance sensors, the magnitude of this error will be influenced by the calibration equation and the sensor normalization procedure used.

The effect of temperature on the apparent soil moisture was small with an average increase in apparent moisture content of 0.05 %/°C for the EnviroSCAN and 0.09 %/°C for the Buddy. The change in apparent moisture content with temperature change was almost linear across the temperature range for the EnviroSCAN while the Buddy readings were more affected by warmer temperature fluctuations (ie 22-38°C) than cooler temperatures (ie 4-22°C). The increase in apparent soil moisture with increasing temperature found in this work for the air and soil is consistent with the findings of Dean *et al.* (1987).

However, Palineau and Starr (1997) found that raw frequency measurements decreased with increasing air temperature but increased with increasing water temperatures. They subsequently predicted that apparent soil moisture should decrease with increasing temperature. However, this prediction is not supported by the observations reported here or by other researchers (eg. Kuraz, 1982; Dean *et al.*, 1987).

The magnitude of the apparent soil moisture increase with temperature was similar to the 0.04 %/°C change in capacitance with increasing temperature reported by Nadler and Lapid (1996, eqn 1). This suggests that the temperature dependent changes observed in this trial are most likely due to either the temperature dependence of the sensor electronics or changes in the medium permittivity but are unlikely to be due solely to water vapour movement. This further suggests that the magnitude or nature of the diurnal fluctuations commonly observed with shallow buried sensors under field conditions may be influenced to some extent by the direct effect of temperature on either the sensor electronics or soil permittivity (Baumhardt *et al.*, 2000). The most likely practical implication is that the magnitude of diurnal stepping commonly associated with both crop extraction and water vapour movement may be reduced or offset and in extreme cases may even be reversed.

Where the capacitance sensors are required to be used for the precision measurement of absolute soil water content (ie. most commonly research trials), there is a need to both calibrate and normalize the instrument to the expected soil conditions. The effect of salinity and temperature on permittivity would be expected to be a function of soil mineralogy, texture and bulk density (Mead *et al.*, 1995). The temperature of the surrounding system influenced the raw count measured in air and water in this trial and would have influenced any subsequent scale frequency and calibration calculations. For example, the calibration of a capacitance system on a soil previously irrigated with low salinity water at a time of comparatively cool conditions may be inappropriate if the subsequent irrigation trial proposes to use highly saline water applied during much warmer months. Hence, concerns over sensor accuracy are most likely to occur where irrigation water is supplied from different sources with vastly different salinity levels throughout the season (ie dam water versus highly saline groundwater) or where sensors are located close to the soil surface (ie likely to experience substantial diurnal and seasonal temperature fluctuations). Under these conditions, it is recommended that instrument normalisation be conducted separately for each water quality being used, and where the water has a temperature similar to the extremes likely to be experienced in the field.

CONCLUSION

The apparent soil moisture content measured using the EnviroSCAN and Buddy capacitance sensors were found to increase with increases in salinity and temperature. The results suggest that the EnviroSCAN is more sensitive to salinity and the Buddy more sensitive to temperature variations over the ranges investigated. However, the magnitude of these variations would be expected to have little, if any, impact on irrigation management decisions for most farms. However, significant variations may be found where highly different irrigation water qualities are used during a season or sensors are subjected to extreme temperature fluctuations. Under these conditions or where accurate absolute measurements of soil water content are required (eg research trials), it is suggested that users of these instruments undertake calibration and normalization measurements which involve the irrigation water quality being used and the temperatures under which the sensors will operate.

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